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'The most important single factor influencing learning is what the pupil already knows. Ascertain this and teach him accordingly'.

(Ausubel 1968 p vi)

The basic premise of this article is that children, as well as adults, have beliefs about how things happen and have expectations which enable them to predict future events (Driver 1979). Moreover, Clement (1977), Nussbaum and Novak (1976), Leboutet-Barrell (1976) and Stead and Osborne (1979) have shown that children, on the basis of their everyday experiences of the world, hold these beliefs and expectations very strongly. In addition young children have clear meanings for words which are used both in everyday language and also in a more specialised way, such as in physics; for example, words like 'work' and even 'electric current' (Osborne and Gilbert 1979). These views of the world, and meanings for words, held by children are not simply isolated ideas (Champagne *et al* 1979a) but rather they are incorporated in conceptual structures which provide a sensible and coherent understanding of the world from the child's point of view.

If the given premise is valid then the learning of physics will not involve merely the absorbing of new information but may entail the modification of the whole or large parts of a student's cognitive structure. As Driver (1979) implies, this will be the case whenever the scientific viewpoint being taught conflicts with the sets of beliefs and expectations held by the student. It might therefore be reasonably argued that the more teachers know about and appreciate the cognitive structures of their students, the more they will be able to provide learning experiences whereby these structures might be modified. From this perspective science learning involves modifying a student's cognitive structure in such a way that the student can explain things both better and more scientifically.

A variety of methods have recently been developed to obtain in-depth descriptions of aspects of a student's cognitive structure. White (1979) has analysed the similarity and differences of some of these methods. Most involve in-depth interviews with students (for example Pines 1977, Deadman and Kelly 1978, Guesne 1978, Brumby 1979, Tiberghien 1979 and Osborne and Gilbert 1979) and the interview schedules provide a variety of ways for gaining insights into aspects of a student's cognitive structure.

In our own work (Osborne and Gilbert 1979) we have placed initial emphasis on exploring student understanding of a single concept (e.g. work, electric current) by means of individual taped interviews. To explore a student's understanding of a particular concept, up to 20 familiar situations are presented to the student, each depicted on a separate card, usually by means of a line drawing (figure 1). The cards normally include both situations which *contain* an instance of the concept and situations which *do not contain* an instance of the concept (instances and non-instances of the concept). Students are asked, for each situation in turn, whether they consider it contains an instance of the concept under consideration or not. The student's reason for his or her choice in each case is then elicited. The interview not only allows students to ask questions to clarify perceived or actual ambiguities before answering, but it also gives flexibility in discussing reasons or lack of reasons for a particular answer.

The interview-about-instances technique described above is at present being used to gain insight into children's and adults' views of the world, and the meanings these people have for the words they use in explaining their views. At the University of Surrey work on a variety of physics concepts is being undertaken (Watts 1980). At the University of Waikato students' concepts of light have been investigated (Stead and Osborne 1979) and a number of studies are in progress as part of a Learning in Science Project (Tasker 1979).

Exploring student views

To provide a clearer appreciation of the nature of the student's views which can be elicited using the interview-about-instances technique, some examples are provided from a recent study in which 40 children and young adults, of average scholastic ability and ranging in age from 7 to 19, were interviewed about the concept *force*. While it is not possible in this article to give a full appreciation of these students' views about force, the following examples based on their responses to the four situations depicted in figure 1 will give some flavour of the partial and nonscientific views that pupils can hold. The examples given are chosen not only because they were typical of this set of interviews but because they bring forth aspects of

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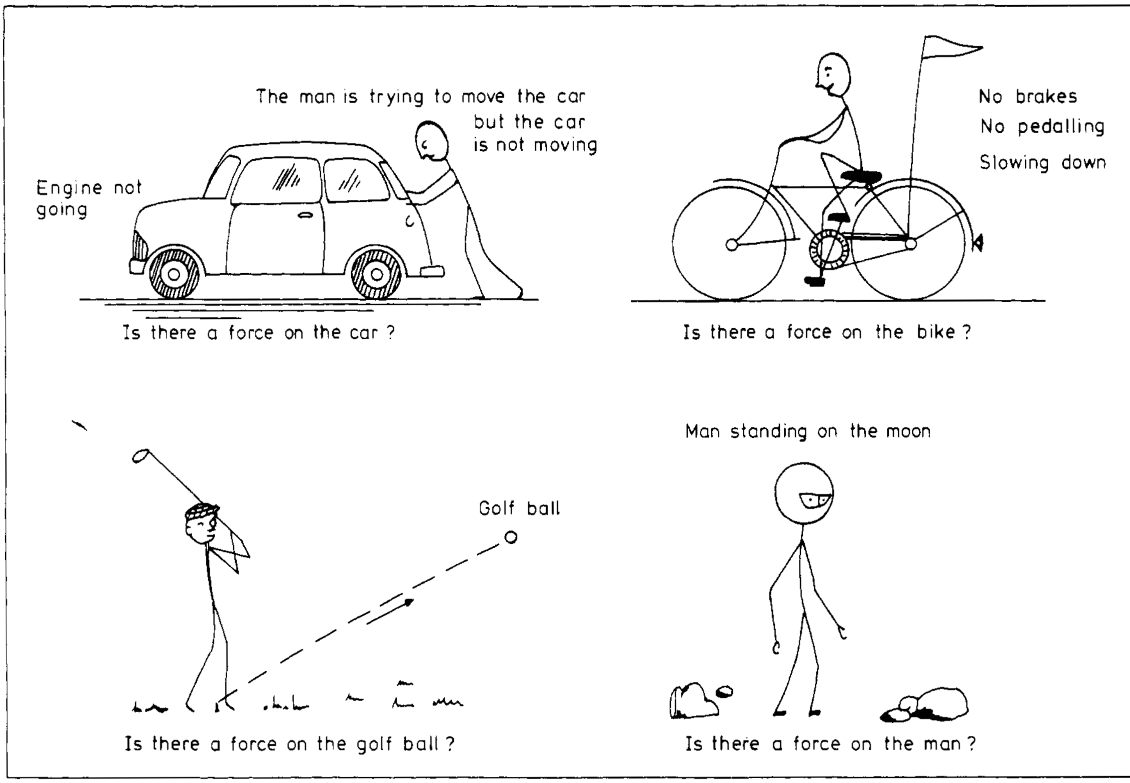

Figure 1 Four examples of the interview-about-instances cards. Students were asked 'In your meaning of the word *force* would you say that there is a force on the . . .?' and then asked 'Why?'

student understanding which we have also identified in interviews on other concepts, notably work and energy. However, apart from stating that the examples given are not uncommon, we are making no statement at this stage about how prevalent these views are.

In these examples, the information in the brackets following each quote is firstly the situation (one of the four in figure 1) and secondly the age in years of the individual whose comment forms the quotation. Where other interviewees of a different age made similar statements their age is also indicated. The 15-year-olds were all involved in integrated science; the 19-year-olds had been exposed to at least two years of secondary school science, O-level integrated science (O) or had completed A-level physics (A).

The various types of nonscientific views and partial understandings that pupils hold include the following.

ANTHROPOCENTRIC AND EGOCENTRIC VIEWS

Young children in particular have anthropocentric and egocentric views. So do some older students. For example,

'No, because it can't feel anything, but there is a force on the man because he has to push it and that puts a force on him'. (car, 9)

'No . . . not really because *he* is not pedalling or anything'. (bike, 9, 11, 13)

'No . . . because there is no gravity and he can move as freely as he wants'. (moon, 11, 13)

Undoubtedly the everyday use of the word *force* as it relates to human action tends to reinforce anthropocentric and egocentric views.

ANIMISM

Younger students sometime endow objects with feeling, a will or a purpose. For example,

'Yes, it is putting force on by itself'. (bike, 9)

'Yes, because it is forcing itself to stop'. (bike, 9)

'Um, I don't think so (but) perhaps the ball could be *trying* to stop'. (golf, 9)

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NONEXISTENCE OF PHYSICAL QUANTITIES

To some students a physical quantity is not present in a given situation unless the effects of that quantity are clearly observable†. For example force is not present unless 'violent motion' is occurring,

'No, because he cannot get it to move'. (car, 11, 13)

'No, if the bike is slowing down on its own accord ... there is not really any force required at all'. (bike, 9, 11, 13)

'I would not think so because in the moon movies they just jump in the air and land 20-30 ft away'. (moon, 11)

REIFICATION OF PHYSICAL QUANTITIES

It is not uncommon for students to endow an object with a certain amount of a physical quantity (force, momentum, velocity). When the quantity runs out the object stops. For example,

'It is just putting force on by itself... from the force you gave it before'. (bike, 9)

'There is a force because of the bike's own mass ... the mass of the bike has come to such a speed that it won't just stop straight away ... the force is still in there ... in the bike ... the force was transferred from the person pedalling ... and it is now still adherent in the bike ... the bike still moves forward'. (bike, 19(A))

'The force from the hit ... it would stop if it wasn't there'. (golf, 13, 15)

'I suppose there is because the force from when he hit it is still on it'. (golf, 9, 11, 13, 15, 19(O), 19(A))

CONFUSION WITH COMMON USAGE OF WORDS

The problem students have in distinguishing between the everyday and technical use of words is not surprising, however it is not only prevalent in younger children. For example,

'Yes, because he is forcing the car'. (car, 9, 11, 13)

'Yes, it is forced through the air by the hit'. (golf, 11, 13, 15, 19(O))

CONTRADICTORY KNOWLEDGE

Students can hold quite contradictory beliefs. For example there were students, even in the 19 age group, who when asked about the force on a man in a satellite (not illustrated) said that there was no air up there and therefore no gravity. When later in the interview they were questioned on the 'moon' instance (figure 1) they stated

'Yes, because there is some gravity on the moon (was there air on the moon?) No'.

Others were more consistent. No air on the moon meant that there was no gravity on the moon either.

CONFUSION BETWEEN PHYSICAL QUANTITIES

Confusion amongst physical quantities was more noticeable with the older students who had been exposed to some physics teaching. They tended to refer to other physical quantities in their responses.

'Yes, the wind as well as the kinetic energy from the golf ball (is that a force?) Yes'. (golf, 19(A))

SUPERFICIAL KNOWLEDGE

Again many older students can glibly quote definitions and also use seemingly appropriate scientific words in their responses. However, the interview-about-instances method can quickly expose the superficial nature of a student's knowledge. For example a student states that friction influences the bike but that there is

'no force, friction is not a force in my meaning of the word'. (bike, 19(A))

The above is not a complete or final list of the viewpoints elicited from students, nor are most of the above categories uniquely elicited by the interview-about-instances method†. However, the categories and quotations are provided to demonstrate the type of understandings which can be exposed by the interview-about-instances method, in addition to the scientifically acceptable views held by students.

Scope and limitations

Over the last two years the interview-about-instances method has been used in over 200 half-hour interviews. These investigations, exploring such concepts as force, work, energy, electric current and light, have enabled us to establish the scope and limitations of the method for investigating student understanding of basic physics concepts.

The method appears to have considerable potential for a variety of reasons. In our experience:

(1) It is applicable over a wide age range;

(2) It is enjoyable for interviewer and interviewee;

(3) It has advantages over written answers in terms of flexibility and depth of the investigation;

(4) Classifying instances is more pertinent and penetrating than asking for a definition;

(5) It is concerned with the student's view rather than merely examining if the student has the correct scientific view.

On the other hand there are some limitations and difficulties:

(1) There is the problem of choosing a limited but adequate set of instances;

(2) The order of instances may influence student responses;

(3) Interviews, and the transcribing and analysis of transcripts, are time consuming;

(4) There are the difficulties associated with interviews and the analysis of the interview data, e.g. difficult to report succinctly.

On balance, however, we consider that the method has considerable potential. We would argue that the

† This viewpoint was particularly noticeable in our investigation of students' concept of light (Stead and Osborne 1979).

† For example, some of the above categories were initially identified by Champagne *et al* (1979b) using a different technique.

insights gained justify the time commitment, while experience overcomes the difficulties pertaining to interviewing.

In addition to using the cards for exploring student understanding, we have also found them valuable for small group discussion in pre-service and in-service teacher training. Not only can the group members attempt to agree on how students are likely to respond and then be shown what responses students typically give, but more importantly discussing the instances between themselves provides an opportunity for teachers to clarify their own views in a non-threatening way. Jackson (1979) has expressed the view that we as physics teachers may well have over-emphasised the mathematical aspects of physics to the exclusion of any admission of the role of language in the representation and development of physical concepts. The cards can be used in a variety of ways in teaching students and in helping them, through discussion, to modify their own concepts toward a more scientifically acceptable viewpoint.

Summary

In a recent paper Shaw and Thomas (1979) suggest that to an external observer learning may appear to be the achievement of certain behavioural objectives. However, for the learner, learning is the revision of his or her own cognitive structure, that is a shift in the way he or she perceives and construes events and behaves in situations. This view of learning implies that an appreciation of the student's view of the world, and the student's meanings for words, needs to be fully appreciated if teaching is to be successful. Physics teachers need to be aware of the various concept understandings that pupils bring to physics class-rooms and thereby appreciate the difficulties pupils may have with understanding physics concepts. It is our view that the information gained using an interview-about-instances method can contribute to this teacher awareness and in doing so can contribute to the improvement of physics teaching.

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